

METHOD OF AND APPARATUS FOR WAVE ENERGY CONVERSION USING A FLOAT WITH EXCESS BUOYANCY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to the technical field of energy generation and particularly to the field of energy generating devices for converting ocean wave energy to electrical energy.

2. Description of the Prior Art

Ocean waves are an attractive source of renewable energy. Ocean wave energy is abundant, more constant than wind and solar energy, well distributed around the globe and near much of the world's population. Nonetheless, little use has been made of ocean wave energy due to the difficulties in converting that energy into a useful form such as electricity.

Most conventional technologies relating to generating electricity from ocean waves focus on extracting ocean wave energy from the motion of the ocean waves as the ocean waves migrate through the energy generating device, either using moving flows or using wind turbines driven by air trapped in enclosures above the waves.

The following nine (9) references are believed to be pertinent to this field of art:

1. United States Patent No. 2,501,696 issued to E. Souczek on March 28, 1950 for "Stream Turbing" (hereafter the "Souczek Patent");
2. United States Patent No. 3,209,156 issued to A. D. Struble, Jr. on September 28, 1965 for "Underwater Generator" (hereafter the "Struble Patent");
3. United States Patent No. 3,965,364 issued to Gustafson et al. on June 22, 1976 for "Wave Generator" (hereafter the "Gustafson Patent");
4. United States Patent No. 4,045,148 issued to Morin on August 30, 1977 for "Turbing" (hereafter the "Morin Patent");
5. United States Patent No. 4,383,182 issued to Bowley on May 10, 1983 for "Underwater Power Generator" (hereafter the "Bowley Patent");
6. United States Patent No. 4,748,808 issued to Hill on June 7, 1988 for "Fluid Powered Motor-Generator Apparatus" (hereafter the "Hill Patent");
7. United States Patent No. 4,850,190 issued to Pitts on July 25, 1989 for "Submerged Ocean Current Electrical Generator And Method For Hydrogen Production" (hereafter the "Pitts Patent");
8. United States Design Patent No. Des.261,639 issued to Robinson on November 3, 1981 for "Water-Driven Electricity Generator" (hereafter the "Robinson Design Patent"); and

9. PCT Patent Publication No. WO 99/20896 published on April 29, 1999 for "Method and Arrangement for Converting Kinetic Energy of Ocean Currents into Rotary Energy" (hereafter the "PCT Publication").

The Souczek Patent disclosed a stream turbine device. The device includes a an underwater carrier wing structure connected to the stream turbine and adapted to create dynamic buoyancy. The underwater carrier wing structure is connected to one end of an elongated holding device. The other end of the holding device is anchored at the bottom of the water course.

The Struble Patent disclosed an underwater generator unit. The unit includes a body portion having waterproofed stator elements mounted in the exterior surface of the body portion. The unit also includes a shaft for rotatively securing an impeller assembly.

The Gustafson Patent disclosed a device for utilizing energy stored in wave motion. The device includes a buoyant body on the water surface is anchored so as to permit free, unrestricted vertical movement when acted upon by a heaving wave. An energy collecting device is connected to the buoyant body and located at a depth where the water is not subjected to the vertical wave motion.

The Morin Patent disclosed a turbine with a water-driven motive element adapted for being immersed in a body of water. The motive element includes a disc having a density close to that of the water in which it is immersed. The disc is horizontally disposed and has a plurality of cells containing a mixture of liquid and gas and the disc carries on the upper and lower surfaces thereof a plurality of blades which are pivotably movable about a horizontal axis. Each blade has one or more pocket containing a mixture of gas and a liquid such that the density of the blades connected to the upper surface of the disc is less than that of water and the density of the blades connected to the lower surface of the disc is greater than that of water. The disc carries

a structure which holds the blades in one direction of pivotal movement when the blades reach a vertical position. Under the action of water current, the blades are driven to their vertical position and effect rotation of the disc, which serves to drive an electrical generator system.

The Bowley Patent disclosed an apparatus and method for generating electrical power. The apparatus includes a plurality of power producing modules disposed in a substantially constant velocity ocean current. The method includes the steps of mechanically coupling the output of the modules to drive a single electrical generator.

The Hill Patent disclosed a fluid powered motor-generator apparatus. The apparatus includes a generator having a power output and a mechanically driven input. The generator has a generally streamlined motor body rotatably mounted to drive the generator input. The motor has a plurality of radially extending generally V-shaped fins mounted on an outside surface thereof. The fins are mounted on brackets above an outer surface of the motor body and have a convex pointed side facing in the direction of rotation and a concave open side facing in a direction opposite to the direction of rotation. As a result, the action of a stream of fluid on the fins tends to rotate the motor the motor body and drive the generator. If the motor-generator apparatus is mounted in water, the generator can be enclosed in another streamlined body which is anchored to the bed of the body of water. A third streamlined motor body can be attached to the bottom of the generator body with a plurality of radially extending fins oriented to cause it to rotate opposite to the direction of rotation of the first streamlined motor body.

The Pitts Patent disclosed a system and method for generating chemical energy from ocean current energy. The system includes a unique suspension system having a support cable submerged below the ocean surface in an isolation zone remote from the adverse influences of storms and hurricanes. The support cable is submerged by a first anchor which includes guys, buoyancy chambers and guy anchors. A second anchor is provided by generator cable assemblies which suspend a plurality of electric energy generating units and are anchored by

means of suspension anchors. Buoyancy provided by modules exert a buoyancy on the suspension system and provides that the basic components of the suspension system essentially support their own weight. In this manner, little or no weight is exerted on support cable by the anchors and generating units suspended. In a preferred embodiment, the generating units are arranged in a matrix of vertical and horizontal rows across the width and along the depth of the ocean current.

The Robinson Design Patent disclosed a water-driven electricity generator.

The PCT Publication disclosed a method and arrangement for converting kinetic energy of ocean currents into rotatory energy. The arrangement includes one or more turbines which is arranged to extend substantially vertically from a buoy anchored in such a way in an ocean current that it cannot rotate with the turbine and driving an electric generator or another rotary machine. At the bottom of the turbine, a counterweight is provided to retain the turbine substantially vertically at normal speed of the ocean current but to permit it to assume an inclined position when subjected to temporarily increased current speeds, thereby protecting the turbine from harmful flexural stresses and protecting the rotary machine from being overloaded.

While many of the above cited references have described systems and/or method for generating electric energy from ocean current, these conventional devices are mostly relying on generating electricity from the migration of the ocean waves and focusing on extracting ocean wave energy from the motion of the ocean waves as the ocean waves migrate through the energy generating device, by using either moving flows or using wind turbines driven by air trapped in enclosures above the waves.

In addition, the conventional energy generating devices are also limited in their efficiency by the difficulty in transforming high forces at low speeds into lower forces at higher speeds needed for electricity generation. Most of these conventional devices are further

compromised by the necessity of operating at the ocean surface where they are exposed to storms and effected by tides. The installations of such conventional devices tend to be extremely large in comparison with the useful energy produced.

Therefore, it is desirable to provide a novel and unique device for generating electrical energy from ocean waves by utilizing migrating pressure fluctuations in ocean waves by utilizing an excessively buoyant float held beneath the water surface which is free to move horizontally within a limited range.

SUMMARY OF THE INVENTION

The present invention is directed to a method of and apparatus for generating electricity from ocean waves by utilizing a float with excessive buoyancy.

Most existing technology aims to extract wave energy from the motion of the liquid as waves migrate through it, either using moving floats or using wind turbines driven by air trapped in enclosures above the waves. Such devices are limited in their efficiency by the difficulty in transforming high forces at low speeds into the lower forces and higher speeds needed for electricity generation . Most of these devices are also compromised by the necessity of operating at the ocean surface where they are exposed to storms and effected by tides. As a general rule, the installations are extremely large in comparison with the useful energy produced.

The present invention is able to overcome many difficulties with existing concepts because it operates on a fundamentally different principle. Rather than being driven by the motion of the water in the waves, it is driven by the pressure fluctuations that travel waves.

In summary, the present invention is directed to a methodology of and an installation for extracting energy from a liquid in which pressure variations are present in the form of migrating surface waves and where it is possible to affix a device to a solid bottom or other structure that does not move vertically with the surface swell. Such an installation is particularly suitable for use in extracting energy from water at sea.

The basic embodiment of the present invention includes a float with excessive buoyancy tethered to the ocean floor. The tether keeps the float beneath the ocean surface in spite of the excessive buoyancy. It also allows the float to move horizontally in response to fluctuations in pressure in the region of the float. The pressure in the water is directly dependent on the depth beneath the surface. The buoyancy of the float creates a force perpendicular to the isobaric

surfaces of the ocean wave. The float moves back and forth as the slope of the isobaric surfaces change which occurs as the ocean waves pass over the region where the float is moored. A turbine is held by and moves with the float for generating electricity.

In the present invention, the float with excessive buoyancy goes through the following phases or stages in a typical operation:

At the first stage, the float is directly above the mooring and the isobaric surface is sloping to the right. The float is forced to the right towards the wave trough because of the slope of the isobaric surfaces that mimic the wave shape.

In a second stage, the float is forced back to the left as the wave crest approaches because now the isobaric surfaces are sub-horizontal while the tether is pulling at an angle.

In the next stage, the float is once again directed above the mooring so the tether is not pulling horizontally but the wave crest has passed to the right so that the isobaric surface now slopes to the left. The resultant force vector is still directed to the left and the float continues to move in that direction.

At the last stage as the next trough passes over the float, the buoyancy vector again points vertically and the angle on the tether pulls the float to the right. The float now cycles back to the geometry of the initial stage.

The present invention has many important advantages, including its efficiency in energy conversion, its unobtrusiveness, its unaffectedness by ocean tides, its protection against storms, its omni-directionality, its ability to convert energy from both waves and currents, its scalability, and its simplicity.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring particularly to the drawings for the purpose of illustration only and not limitation, there is illustrated:

FIG. 1 is an illustrative diagram showing the basic structures and principles of the present invention method of and system for generating electricity from ocean waves by utilizing a float with excessive buoyancy which is tethered by an mooring on the ocean floor and supports a turbine for generating electricity;

FIG. 2A is an illustrative diagram demonstrating the first phase which the present invention float with excessive buoyancy goes through in a typical operation;

FIG. 2B is an illustrative diagram demonstrating the second phase which the present invention float with excessive buoyancy goes through in a typical operation;

FIG. 2C is an illustrative diagram demonstrating the third phase which the present invention float with excessive buoyancy goes through in a typical operation;

FIG. 2D is an illustrative diagram demonstrating the fourth and last phase which the present invention float with excessive buoyancy goes through in a typical operation;

FIG. 3A is an illustrative diagram demonstrating a horizontal axis turbine utilized in the present invention system for generating electricity from ocean waves

FIG. 3B is an illustrative diagram showing a vertical axis turbine utilized in the present invention system for generating electricity from ocean waves

FIG. 3C is an illustrative diagram showing an alternative vertical axis turbine utilized in the present invention system for generating electricity from ocean waves;

FIG. 4A is an illustrative diagram showing electrical cable connection between an offshore generator and an onshore power conditioning and storage installation;

FIG. 4B is an illustrative diagram showing electrical cable connection between a group of offshore generators and the onshore power conditioning and storage installation;

FIG. 5A is an illustrative diagram showing an embodiment of the present invention system for shallow water installation;

FIG. 5B is an illustrative diagram showing an alternative embodiment of the present invention system for shallow water installation;

FIG. 6 is an illustrative diagram showing an embodiment of the present invention system where the float with excessive buoyancy is tethered by multiple moorings and tethers for deep water installation;

FIG. 7 is an illustrative diagram showing an alternative embodiment of the present invention system for deep water installation;

FIG. 8A is an illustrative diagram showing an embodiment of the present invention system for open ocean installation;

FIG. 8B is an illustrative diagram showing other applications of the principles of the present invention system utilizing a float with excessive buoyancy.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Although specific embodiments of the present invention will now be described with reference to the drawings, it should be understood that such embodiments are by way of example only and merely illustrative of but a small number of the many possible specific embodiments which can represent applications of the principles of the present invention. Various changes and modifications obvious to one skilled in the art to which the present invention pertains are deemed to be within the spirit, scope and contemplation of the present invention as further defined in the appended claims.

The present invention is a method of and a system for generating electricity from migrating pressure fluctuations in a fluid under the principle of excess buoyancy which is implemented by utilizing an excessively buoyant float held beneath the surface of the fluid and free to move horizontally within a limited range.

Referring to Figure 1, there is shown a basic arrangement of the present invention. In a preferred embodiment, the present invention wave energy conversion system **100** is installed beneath an ocean surface **10**. The present invention wave energy conversion system **100** includes a float **110** with excessive buoyancy which is held by a tether **120** to the ocean floor **20**. The tether **120** is moored by a mooring **130** and keeps the float **110** beneath the ocean surface **10** despite the excess buoyancy, and allows the float **110** to move horizontally in response to fluctuations in pressure in the region of the float **110**.

The pressure in the water is directly dependent on the depth beneath the air /liquid interface, *i.e.*, the ocean surface **10**. Therefore, for example, the pressure at the same depth is the same regardless of whether it is in a wave crest **12** or trough **14**, as depicted by the isobaric surfaces **16** (which is defined by hydrostatic pressure that corresponds with the depth of the water).

Buoyancy of the float **110** creates a force **B** which is perpendicular to the isobaric surfaces **16**. The tether **120** also exert a force **T** on the float **110** along th downward direction of the tether **120**. The resultant force **F** from the combined influence of the buoyancy force **B** and the tether force **T** fluctuates with the wave and tether geometries and drives the float **110** back and forth as the slope of the isobaric surfaces **16** change, which occurs as waves cross over the region where the system is moored.

The present invention wave energy conversion system **100** also include a turbine device attached to the float **110** (or tether **120**) for generating electricity as the float **110** moves through the water.

Referring to Figures 2A through 2D, which demonstrates the phases the present invention system **100** goes through in a typical operation.

At the first stage shown in Figure 2A, the float **110** is directly above the mooring **130** and the water surface **10** is sloping to the right as shown by the wave propagation direction arrow **W**. The float **110** is forced to the right, towards the wave trough **14**, because of the slope of the isobaric surfaces **16** that mimic the wave shape.

At the second stage as shown in Figure 2B, the float **110** is forced back to the left as the wave crest **12** approaches because now the isobaric surface **16** is sub-horizontal while the tether force **T** is pulling the float **110** at an angle.

At the thirds stage as shown in Figure 2C, the float **110** is once again directly above the mooring **130** (not shown) so the tether force **T** is not pulling the float **110** vertically, but the wave crest **12** has passed to the right so the ocean surface **10** (as well as the isobaric surface **16**) now slopes to the left. The resultant force **F** is still directed to the left and the float continues to move in that direction.

At the fourth and last stage as shown in Figure 2D, as the next trough **14** passes over the float **110**, the buoyancy force **B** again points up vertically and the angle on the tether force **T** pulls the float **110** to the right. The float **110** now cycles back to the geometry of the first stage shown in Figure 2A.

The potential to generate electric power or get other useful work from the present invention system **110** is afforded by the fact that the excessive buoyancy float **110** moves with respect to the fluid and/or with respect to the ground. Any mechanism that couples between the float and either of these other media will suffice. In the preferred embodiments of the present invention, the system **100** utilizes propellers on electric generators affixed to the float **110** or tether **120**, as illustrated in Figures 3A through 3C.

The embodiment shown in Figure 3A utilizes a horizontal axis turbine **142** affixed to the tether **120** immediately beneath the float **110**. The entire turbine **142** is free to rotate around a vertical axis so that it can adjust to the shifting directions of the float motion.

An alternative embodiment shown in Figure 3B utilizes a vertical axis turbine **144** that is installed beneath the float **110**. The vertical axis turbine **144** benefits from the fact that it needs no reorientation to adjust for changes in the float movement direction.

Another embodiment utilizing a vertical axis turbine **146** is shown in Figure 3C. In this embodiment a 3-cup rotor is placed on a vertical axis, above or below the float **110**, and affixed to an electric generator.

In addition to these single turbine designs shown in Figures 3A through 3C, multiple turbines may also be attached to the float **110** or tether **120** in order to take advantage of the locations where the wave pressure fluctuations are accelerated around the float **110** or keep the size of individual turbines with a practical limit.

Referring to Figure 4A, electric power generated offshore by the generators in the present invention system **100** can be transported to shore through a conductive underwater cable **150** that follows the tether **120** to the ocean floor **20** and then extends along the ocean floor **20**. The onshore facility **160** can condition the power to damp out fluctuations in the power supply. It can also contain batteries or capacitors for energy storage.

Referring to Figure 4B, there is illustrated an arrangement with multiple installations of the present invention system **100**. There are situations where it would be preferable to use an array of the present invention system **100**. For example, there may be a practice limit to the amount of power a single installation can generate depending on the factors such as the size of the wave pressure fluctuation, environmental concerns about the amount of wave disruption and the size of the vessel that install the system. In these situations multiple installations can be deployed to generate more power than a single installation. Also, multiple installations can be linked to generate more continuous energy. For a single installation the float motion is oscillatory and the power generated will fluctuate. One way to provide a more constant supply of electricity on land is to use multiple installations and place them different distances from shore so that they achieve peak power at different times. If two installations are separated by a distance equal to one half the wave length then one will be yielding peak power when the other is yielding minimum power, and vice versa.

The primary purpose of the present invention system **100** is to generate electricity or other useful work from the oscillatory motion induced by pressure variations associated with waves. However, if the electricity is generated using turbines that turn when the float moves through the water, then it will also be possible to get additional energy from any mass movement of the water with respect to the system. For example, when the system is affixed to the ocean floor it can benefit from the movement of water in currents, near river outlets or anywhere that the water is moving relative to the ocean floor.

A critical aspect of the functioning of the present invention system **100** is that the attachment to the ocean floor allows some degree of horizontal motion but restricts that motion when the horizontal excursion gets too large. The single tether mooring design shown in Figures 1 through 4B achieves these characteristics because it provides minimal resistance for small excursions while provides a strong restoring force for large excursions. However, it is not useful to place the single tether configuration in water that is too shallow because the tether will become overly restrictive on horizontal motion. Nonetheless, in many instances it would be desirable to have a energy generating system that would function effectively in shallow water settings. For example, there is power loss associated with the length of the electric cable that connects the system to the place where the energy is needed, so if the ocean depth increases very slowly away from the shoreline the power losses many be significant because the system would have to be so far away. In addition, it may also be favorable to operate the system in shallower water because shallower depths to the ocean floor increase the relative size of waves, decrease their wave length, and thus result in steeper pressure gradients.

Referring to Figures 5A and 5B, there are shown two alternative embodiments of the present invention system for shallower water. In the embodiment shown in Figure 5A, the tether **120** is moored to the ocean floor **20** at its two opposite ends. The float **110** is affixed to the tether **120** by one or more rollers **170** that allow the float **110** to oscillate horizontally in the direction of wave travel. Because the float **110** moves with respect to the tether **120**, it offers a new way of generating electricity by coupling to the rotation of the rollers **170**. An additional option is to place fixed magnets (not shown) on either the float **110** or the tether **120** and use the other member as a linear generator.

In the embodiment shown in Figure 5B, the shallow water installation utilizes a track **180** installed on or near the ocean floor **20** and supported at its two opposite ends by track anchors **182** and **184** to have the float **110** run on the track **180**. The track **180** may be arched in its middle portion or curved at its ends to stop the float **110** at the end of its desired travel and to

provide the restoring force that returns the float **110** towards the center of travel. Again, the motion of rollers **170** may be used to extract energy, or the linear generator option may be used.

Referring to Figures 6 and 7, there are shown alternative embodiments of the present invention system for deeper water. There may be a problem with the single tether installation in water that is too deep because a single tether will not provide significant restoring force to the float.

As shown in Figure 6, if a deep water installation is desired, it can be accomplished by having the tether branch out below a certain depth to connect to the ocean floor **20** in multiple mooring locations **130** so that the branching point will be held stationary despite the horizontal excursions of the float **110**. This geometry also affords the opportunity to adjust the effective tether length by adjusting the depth as which the multiple tethers join into a combined tether. One mechanism that binds the tethers **120** together may be a moveable “collar” **142**, which can be adjusted, by moving it up or down to change the distance between the float and the tether joining point, to “tune” the entire installation to an ideal geometry depending on changes in the ocean wave characteristics.

Adjusting the natural frequency of the apparatus has a large influence on power generation because when the installation achieves a natural resonance with the waves the excursions, speeds and forces will all increase. If the natural frequency can be adjusted in situ then there is a potential to keep the installation tuned for maximum power output as conditions change.

“Tuning” of the installation can also be achieved by other means besides moving the collar on the multi-tether installation. As an example shown in Figure 7, tuning can be achieved by any suitable device, such as an electronic winch **112**, that can adjust the length of the tether **120** beneath the float **100**.

In some applications it may be desirable to extract wave energy far from shore or in extremely deep water. In these applications it may be impractical to moor the installation to the ocean floor. Nonetheless,

The present invention method and system have many advantages. The following are some of the more important advantages of the present invention:

1. Conversion efficiency

Efficiency is always compromised when converting the slow-speed motion of the water to the high-speed movement needed in the generator that creates electricity. This device has a significant advantage over other devices because it moves horizontally through the water several times faster than the water itself moves within the waves.

2. Unobtrusive

The installation resides entirely beneath the ocean surface and thus has no impact on the aesthetics of the installation site. In addition, it operates silently which is preferable in comparison various surface installations that use air driven turbines.

3. Unaffected by tides

Typical wave energy devices only function at the water/air interface and must be installed in a way that accounts for tidal fluctuations. In contrast, the pressure gradients that drive the present device extend several meters beneath the surface, so it can be placed a few meters below mean sea level, safely below the influence of tidal fluctuations.

4. Storm protection

The subsurface placement also protects the installation from the most violent environmental extremes.

5. Omni-directional

In some modes of installation there is no preferred directionality. Thus the device extracts energy regardless of the incident wave direction.

6. Ocean current energy

The device is unique among most ocean energy extraction devices in that the one device gathers energy from both waves and currents.

7. Scalable

The concept can easily be scaled to any output requirements limited only by the available wave energy. Alternatively, output can be increased by installing several devices that each contribute to the energy delivered to a single onshore station.

8. Simplicity

Single -tether mooring makes the device comparatively easy to install, and it does not require any additional structure such as a wave- focusing device.

Defined broadly, the present invention is an apparatus for extracting energy from waves in a liquid body, comprising: (a) at least one floating device placed in said liquid body and having a float with excess buoyancy exerting a primarily upward buoyant force on the float along a direction perpendicular to the isobaric surfaces of the liquid body which changes as said waves propagating through the liquid body; (b) the at least one floating device further having means for holding said float with excessive buoyancy in said liquid body, the holding means exerting a primarily downward holding force on said float while allowing said float to move back and forth in a substantially horizontal direction as a result of a substantially horizontal force which is a combination of the holding force and said buoyant force; and (c) means attached to said at least one floating device for generating electricity as said float moves back and forth in said liquid body.

Defined broadly, the present invention is a method of extracting energy from waves in a liquid body, comprising the steps of: (a) placing at least one floating device having a float with excess buoyancy in said liquid body such that the excess buoyancy exerts a primarily upward

buoyant force on the float along a direction perpendicular to the isobaric surfaces of the liquid body which changes as said waves propagating through the water body; (b) holding said float with excessive buoyancy in said liquid body such that a primarily downward holding force is also exerted on said float, while allowing said float to move back and forth in a substantially horizontal direction, as a result of a substantially horizontal force which is a combination of the holding force and said buoyant force; and (c) attaching an electricity generating means to said at least one floating device for generating electricity as said float moves back and forth in said liquid body.

Of course the present invention is not intended to be restricted to any particular form or arrangement, or any specific embodiment, or any specific use, disclosed herein, since the same may be modified in various particulars or relations without departing from the spirit or scope of the claimed invention hereinabove shown and described of which the apparatus or method shown is intended only for illustration and disclosure of an operative embodiment and not to show all of the various forms or modifications in which this invention might be embodied or operated.

The present invention has been described in considerable detail in order to comply with the patent laws by providing full public disclosure of at least one of its forms. However, such detailed description is not intended in any way to limit the broad features or principles of the present invention, or the scope of the patent to be granted. Therefore, the invention is to be limited only by the scope of the appended claims.

WHAT IS CLAIMED IS: